MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2019/2020

EEE7256 – DEVICE PROCESSING AND FABRICATION

(Master of Electrical and Electronic Engineering)

21 OCTOBER 2019
2.30 p.m – 5.30 p.m
(3 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 7 pages with 3 Questions only.
2. Attempt **ALL** questions. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

QUESTION 1

(a) In Czochralski (CZ) process, the crucible in a CZ chamber is loaded with chunks of the electronic grade silicon (EGS) and small amounts of dopant material, in order to grow single crystal silicon (Si) boule from the molten EGS and the dopant material.

(i) Describe briefly why pure EGS cannot be used directly for the fabrication of the semiconductor devices. [2 marks]
(ii) List down SIX requirements for the crucible material intended for the CZ process. [3 marks]
(iii) With schematic diagram, describe the process involved in the CZ crystal growth technique. [2+7 marks]
(iv) Describe the shortcomings of the Si crystals grown using the CZ crystal growth technique. [2 marks]

(b) During a crystal growth process, 200 g of Si is mixed with 10 g of boron (B) in the crucible of the crystal grower. During the melting process taking place in the crucible, all B atoms are dissolved into the Si and these B atoms are fully ionized. The atomic weight of B is 11. The charge carrier mobility, μ, of the doped Si is 1200 $cm^2V^{-1}s^{-1}$, density of molten silicon is 2.3 gcm^{-3}, Avogadro constant, N_A, is 6.02 $x10^{23}$ mol^{-1}, and electronic charge, q, is 1.602×10^{-19} coulombs.

(i) Calculate the carrier concentration of the B atoms in the doped Si. [3 marks]
(ii) Calculate the conductivity of the doped Si. [2 marks]

(c) The design and development efforts in utilizing computer hardware and software technology to improve manufacturing methods have led to the deployment of computer-integrated manufacturing of integrated circuits (IC-CIM) techniques in the fabrication of the microelectronic integrated circuits. Describe the objectives of the deployment of the IC-CIM techniques. [4 marks]

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QUESTION 2

(a) In semiconductor fabrication, thermal diffusion and ion implantation are the two common techniques used to introduce dopants into semiconductors in order to realize variety of microelectronic devices.

(i) Compliment the following characteristics of the thermal diffusion and ion implantation processes, respectively, given in Table 2(a). [6 marks]

Table 2(a)

Characteristics	Thermal Diffusion	Ion Implantation
Isotropic/Anisotropic		
Process Temperature		
Control on Dopant Dose		
Equipment Costing		
Throughput		
Shallow Junction		

(ii) A p-type silicon (Si) wafer with a background concentration of 2×10^{15} cm^{-3} is doped with phosphorus (P) dopants following the drive-in diffusion process at a temperature of 950 °C for 40 minutes. At the end of the doping process, the P dopant concentration at the surface of the wafer is 1×10^{18} cm^{-3}. It is given that the diffusivity of P in Si is 1×10^{-16} cm^2s^{-1} at 950 °C. Determine the dose of the P atoms for the diffusion process. Calculate the junction depth. [6 marks]

(iii) In an ion implantation process, arsenic (As) is implanted in Si wafer in order to create an n-doped region within the Si wafer. The projected range of the implanted profile is 2000 Å. Given the standard deviation of the projected range as 400 Å. Determine the depth of peak of the implanted profile, and the peak concentration of the As dopants for an implantation dose of 10^{13} cm^{-2} adopted in the implantation process. [3 marks]

(b) Physical vapor deposition (PVD) techniques are the mainstream techniques for growing contact films in microelectronic fabrication.

(i) Identify a PVD technique to grow a contact film, which is intended to be a polycrystalline metal alloy layer. Justify your selection. [3 marks]

(ii) Discuss the working principle for the PVD technique identified in Question 2(b)(i). [2+6 marks]

(iii) Describe the advantages of the PVD technique identified in Question 2(b)(i). [5 marks]

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QUESTION 2

(c) Photolithography is an optical mean for transferring patterns onto a substrate via an imagable photoresist layer.

(i) Describe the procedures involved in photolithography process in patterning a layer on a substrate. [6 marks]

(ii) Compliment TWO advantages of the contact, proximity and projection exposure system in the photolithography process, respectively. [6 marks]

(iii) A mask exposure system uses an *i*-line source with wavelength of 365 nm. If the photoresist thickness is 1.3 μm and the photoresist constant is 0.75, determine the minimum feature size, W_{min}, that can be achieved by using a hard contact mask aligner, and a mask aligner with an air gap of 10 μm, respectively. [4 marks]

(iv) Compliment the following characteristics of the wet etching and dry etching processes, respectively, given in Table 2(c)(iv) [6 marks]

Table 2(c)(iv)

Characteristics	Wet Etching	Dry Etching
Isotropic/Anisotropic		
Equipment Costing		
Throughput		
Selectivity		
Etch Control		
Etch Rate		

(d) In semiconductor device fabrication, copper (Cu) films are used more and more often instead of aluminum (Al) films in contact metallization scheme. Explain why Cu film is preferred over Al film. List down the main drawbacks of the Cu metallization scheme. [7 marks]

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QUESTION 3

The cross-sectional view of a monocrystalline silicon (Si) solar cell with aluminum (Al) front contact grids and back contact is given in Figure 3. The monocrystalline Si solar cell can be patterned using photolithography technique for the n^+ Si region and the Al front contact grids.

(i) Design a fabrication process for the monocrystalline solar cell starting from the p-type Si wafer. Illustrate each processing step. [10 marks]

(ii) Determine the number of the photolithography masking step involved in the making of the solar cell. [1 mark]

(iii) Describe the distinctive material characteristic, advantage and disadvantage of the monocrystalline solar cells over other photovoltaic technologies. [4 marks]

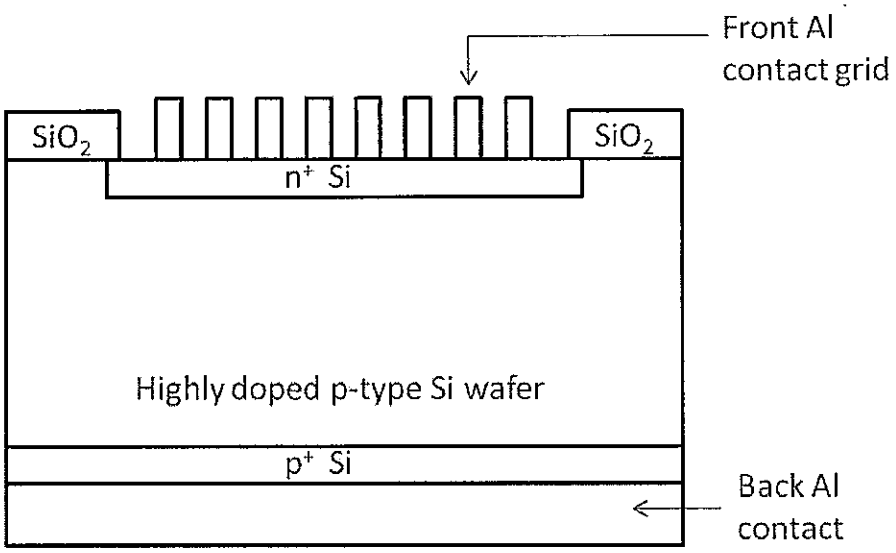

Figure 3: Schematic cross-section of a monocrystalline Si solar cell.

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Values of the error function $\operatorname{erf}(t) = \frac{2}{\sqrt{\pi}} \int_0^t e^{-a^2} da$

t	0	1	2	3	4	5	6	7	8	9
0.0	0.000	0.0113	0.0226	0.0338	0.0451	0.0564	0.0676	0.0789	0.0901	0.1013
0.1	0.1125	0.1236	0.1348	0.1459	0.1569	0.1680	0.1790	0.1900	0.2009	0.2118
0.2	0.2227	0.2335	0.2443	0.2550	0.2657	0.2763	0.2869	0.2974	0.3079	0.3183
0.3	0.3286	0.3389	0.3491	0.3593	0.3694	0.3794	0.3893	0.3992	0.4090	0.4187
0.4	0.4284	0.4380	0.4475	0.4569	0.4662	0.4755	0.4847	0.4937	0.5027	0.5117
0.5	0.5205	0.5292	0.5379	0.5465	0.5549	0.5633	0.5716	0.5798	0.5879	0.5959
0.6	0.6039	0.6117	0.6194	0.6270	0.6346	0.6420	0.6494	0.6566	0.6638	0.6708
0.7	0.6778	0.6847	0.6914	0.6981	0.7047	0.7112	0.7175	0.7238	0.7300	0.7361
0.8	0.7421	0.7480	0.7538	0.7595	0.7651	0.7707	0.7761	0.7814	0.7867	0.7918
0.9	0.7969	0.8019	0.8068	0.8116	0.8163	0.8209	0.8254	0.8299	0.8342	0.8385
1.0	0.8472	0.8468	0.8508	0.8548	0.8586	0.8624	0.8661	0.8698	0.8733	0.8768
1.1	0.8802	0.8835	0.8868	0.8900	0.8931	0.8961	0.8991	0.9020	0.9048	0.9076
1.2	0.9103	0.9130	0.9155	0.9181	0.9205	0.9229	0.9252	0.9275	0.9297	0.9319
1.3	0.9340	0.9361	0.9381	0.9400	0.9419	0.9438	0.9456	0.9473	0.9490	0.9507
1.4	0.9523	0.9539	0.9554	0.9569	0.9583	0.9597	0.9611	0.9624	0.9637	0.9649
1.5	0.9661	0.9673	0.9684	0.9695	0.9706	0.9716	0.9726	0.9736	0.9746	0.9755
1.6	0.9764	0.9772	0.9780	0.9789	0.9796	0.9804	0.9811	0.9818	0.9825	0.9832
1.7	0.9838	0.9844	0.9850	0.9856	0.9861	0.9867	0.9872	0.9877	0.9882	0.9886
1.8	0.9891	0.9895	0.9899	0.9904	0.9907	0.9911	0.9915	0.9918	0.9922	0.9925
1.9	.99279	.99309	.99338	.99366	.99392	.99418	.99443	.99466	.99489	.99511
2.0	.99532	.99552	.99572	.99591	.99609	.99626	.99642	.99658	.99673	.99688
2.1	.99702	.99715	.99728	.99741	.99753	.99764	.99775	.99785	.99795	.99805
2.2	.99814	.99822	.99831	.99839	.99846	.99854	.99861	.99867	.99874	.99880
2.3	.99886	.99891	.99897	.99902	.99906	.99911	.99915	.99920	.99924	.99928
2.4	.99931	.99935	.99938	.99941	.99944	.99947	.99950	.99952	.99955	.99957
2.5	.99959	.99961	.99963	.99965	.99967	.99969	.99971	.99972	.99974	.99975
2.6	.99976	.99978	.99979	.99980	.99981	.99982	.99983	.99984	.99985	.99986
2.7	.99987	.99987	.99988	.99989	.99989	.99990	.99991	.99991	.99992	.99992
2.8	.99992	.99993	.99993	.99994	.99994	.99994	.99995	.99995	.99995	.99996
2.9	.99996	.99996	.99996	.99997	.99997	.99997	.99997	.99997	.99997	.99998
3.0	.99998	.99998	.99998	.99998	.99998	.99998	.99998	.99999	.99999	.99999

for $t > 3$ $\quad \operatorname{erf}(t) \approx 1 - \frac{1}{\sqrt{\pi}\, t} \exp(-t^2)$

erfc (t) = 1 - erf (t)

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APPENDIX **Physical Constants:**

Avogadro number, $N_{avo} = 6.02217\times10^{23}$ mol^{-1}
Boltzmann constant, $k = 1.380622\times10^{-23}$ J K^{-1} = 8.61712×10^{-5} eV K^{-1}
Electronic charge, $e = 1.60219\times10^{-19}$ C
Electron rest mass, $m_o = 9.10956\times10^{-31}$ kg
Electron volt, 1 eV = 1.60219×10^{-19} J
Si yield strength = 2×10^{7} dynes cm = 7 GPa
Latent heat of fusion for Si, L = 340 cal g^{-1}
Thermal conductivity of Si, k = 0.21 W cm^{-1} °C^{-1}
Amount of heat of 1 calorie = 4.14 J
Density of bulk Si = 2.33 g cm^{-3}
Density of molten Si = 2.53 g cm^{-3}
Electric current of 1 A = 1 Cs^{-1}
Atomic mass unit of 1 amu = 1.66053×10^{-27} kg
Magnetic flux density of 1 T = 1 Wb m^{-2} = 10^4 G
Angstrom unit of 1 Å = 1×10^{-10} m = 0.1 nm = 1×10^{-4} μm
Permittivity of free space = 8.85×10^{-14} F cm^{-1}
Pressure of 1 Torr = 133.32237 Pa

Formulas:

$C(x,t)=C_s erfc\left[\frac{x}{2\sqrt{Dt}}\right]$	$N(x)=\frac{Q_o}{\sqrt{2\pi}\Delta R_p}e^{\left[-\frac{1}{2}\left(\frac{x-R_p}{\Delta R_p}\right)^2\right]}$
$C(x)=\frac{Q}{\sqrt{\pi Dt}}e^{-\left(\frac{x}{2\sqrt{Dt}}\right)^2}$	$N(R_p)=\frac{Q_o}{\sqrt{2\pi}\Delta R_p}=N_p$
$x_j = 2\sqrt{Dt\ \ln(N_0/N_B)}$	$C_s=\frac{Q}{\sqrt{\pi Dt}}$
$x_j = 2\sqrt{Dt}\ erfc^{-1}(N_B/N_o)$	$Q=2C_s\sqrt{\frac{Dt}{\pi}}$
$k_0=\frac{C_s}{C_l}$	$Q=\sqrt{2\pi}N_p\Delta R_p$
$W_{\min}=\sqrt{k\lambda g}$	$C = k\,C_0\,(1-x)^{k-1}$
$W_{min} = k\,\{\lambda / NA\}$	

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